Ultrasound in the Evaluation of Acute Trauma

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KEYWORDS

- Extended focused assessment with sonography in trauma
- Focused assessment with sonography in trauma • Trauma • Ultrasound

KEY POINTS

- Ultrasound (US) has replaced more invasive methods of evaluating trauma patients.
- US can rapidly identify life-threatening injuries in the chest or abdomen.
- US may be a useful tool for triage in a mass casualty or prehospital setting.
- Like any imaging modality, US has well-known advantages and limitations.

INTRODUCTION

For nearly 3 decades, the focused assessment with sonography in trauma (FAST) examination has been an integral tool for physicians assessing patients with traumatic injuries. Initially met with skepticism,[1] the efficacy of ultrasound (US) in trauma care is now widely recognized, especially when considering the inherent limitations of physical examinations[2,3] and standard radiographic imaging.[4,5] With the introduction of chest US aimed at identifying thoracic pathology (extended FAST [E-FAST]), the limitations of plain film radiography in the evaluation of a trauma patient can be minimized,[6] and the demonstrated utility of US has led to its use in the evaluation of any patient presenting in shock.[7] Despite its advantages, US is not without its own limitations, and awareness of these is essential to prevent potentially life-threatening oversights. This review will explore the current literature on the role, technique, and

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Abbreviations	
BCI	blunt cardiac injury
CAVEAT	chest, abdomen, vena cava, and extremities for acute triage
EASy	echocardiographic assessment using subxiphoid only
E-FAST	extended focused assessment with sonography in trauma
EMS	emergency medical service
FAST	focused assessment with sonography in trauma
FASTER	focused assessment sonography for trauma and extremity and respiratory evaluation
FATE	focus-assessed transthoracic echocardiography
ICS	intercostal space
LUQ	left upper quadrant
MCI	mass casualty incident
RUQ	right upper quadrant
STAR	subcostal to apical, respiratory to parasternal
US	ultrasound

limitations of US in the evaluation of a trauma patient with a focus on each component of the E-FAST examination.

ROLE OF ULTRASOUND IN ABDOMINAL TRAUMA

Background

The initial publications introducing the FAST examination concentrated on detecting free intraperitoneal or pericardial fluid in blunt trauma cases.[8] The use of diagnostic US to evaluate the blunt trauma victim for abdominal injuries has been advocated since the 1970s, but it was not until the 1990s that surgeon-performed abdominal US for trauma was first reported.[9] Since then, numerous studies have demonstrated the utility and advantages of using abdominal US in the initial work-up of the blunt trauma patient.[9–12] As a result, surgeons and emergency physicians have embraced this technology and have integrated US into their standard diagnostic toolkit for abdominal assessments across a variety of patient conditions.[13] Current indications for performing a FAST examination include blunt and penetrating cardiac and chest trauma, trauma in pregnancy, pediatric trauma, undifferentiated hypotension, and even evaluation of medical (nontrauma) patients. While algorithms have been published with flowcharts of how and when the FAST examination should be incorporated into the assessment of the trauma patient, the reality is that the FAST examination can be used any time, including prehospital.[14] The FAST examination continues to remain a standard part of the trauma evaluation due to its simplicity, availability, and versatility.[13]

Technique

A low-frequency (3.5 MHz) transducer is ideal. Both curvilinear and phased array probes are sufficient. Probe selection may be related to some views being difficult to obtain due to the patient's anatomy or body habitus. The patient should be positioned supine. The original FAST examination consisted of 3 views of the abdominal examination: the right upper quadrant (RUQ) (**Fig. 1**), the left upper quadrant (LUQ) (**Fig. 2**A, B), and the pelvis to rule out bleeding in the abdomen from trauma (**Fig. 3**A–C).[12] The sequence of obtaining images is not critical as the location of free fluid does not directly correlate with the associated organ injury; however, inadequate imaging of the 3 abdominal regions can lead to false negative interpretation.[15] For both the RUQ and LUQ, imaging of the superior and inferior poles of the kidney

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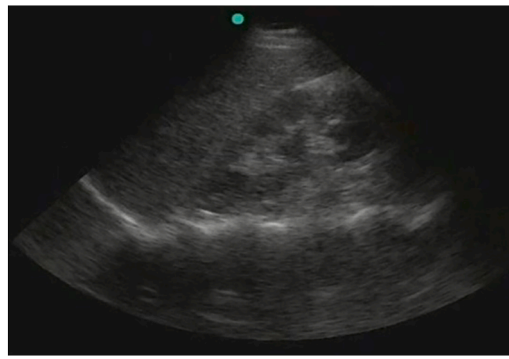

Fig. 1. Normal right upper quadrant view.

adjacent to the solid organ is pivotal to accurate interpretation. Additionally, scanning the US probe throughout the hepatorenal and splenorenal recesses from anterior to posterior will ensure adequate evaluation in these dependent regions. For the pelvic region, US images of both the transverse and sagittal views of the pelvic region through a full bladder will provide the best imaging of the dependent pelvic region.[16] Similarly, scanning the US probe throughout the pelvic region (anteriorly to posteriorly and superiorly to inferiorly) are necessary for a complete FAST examination to determine if intraabdominal free fluid is present after trauma.

Limitations

Despite the obvious advantages of the FAST examination in trauma including high diagnostic specificity, there are several limitations that one must be aware of, especially the low sensitivity of the abdominal portion of the examination. False positive and false negative US studies can occur due to poor image acquisition, amount of intraabdominal fluid present during examination, operator experience, body habitus, or a combination of these factors. US does not adequately evaluate the retroperitoneum or hollow organs for traumatic injuries.[17,18] Additionally, US does not reliably detect solid organ injuries, as fresh clot has the same density as the organ itself.[19] One study showed that 26% of computerized tomography (CT)-diagnosed solid organ injuries had no evidence of free fluid.[18] A recent meta-analysis reported a pooled sensitivity of only 79%.[20] Up to 29% of abdominal injuries may be missed if blunt

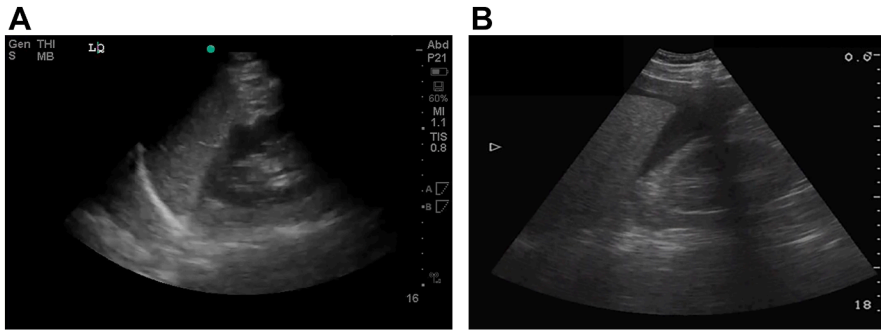

Fig. 2. Normal (*A*) and positive (*B*) left upper quadrant views.

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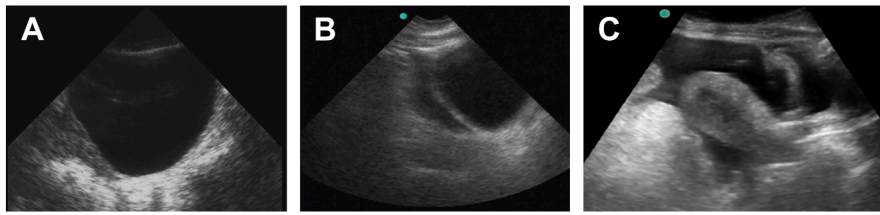

Fig. 3. Normal (*A*), positive transverse (*B*), and positive longitudinal (*C*) pelvis views.

trauma patients are evaluated with the FAST examination as the sole diagnostic tool.[1,21] Even if fluid is detected, this finding is of limited value in a hemodynamically stable patient.[22]

Other patient factors can lead to errors with interpretation. For example, female patients of reproductive age frequently exhibit small amounts of physiologic fluid in the Pouch of Douglas and many studies fail to address FAST examination findings in pregnancy.[16,23] Men with prominent seminal vesicles can both be misinterpreted as traumatic free fluid.[16] Obesity makes obtaining the views more difficult and has increase diagnostic inaccuracy,[13] and it is also very difficult to differentiate ascites from blood,[24] and there are reports of false positive FAST examinations in patients who were found to have free fluid from over resuscitation.[25] A finding called the "double line sign" represents another frequent false positive finding with interpreters mistakenly identify perinephric fat as free fluid in Morison's pouch during the FAST examination in up to 27% of cases.[26]

In penetrating abdominal trauma, several studies have demonstrated that a negative FAST examination does not rule out significant intraperitoneal injury after penetrating torso trauma and other diagnostic.[27] However, a positive FAST examination should increase suspicious for serious injury that requires laparotomy. Finally, failure to conduct a thorough and precise examination may result in overlooking subtle collections of free fluid in the chest or abdomen, potentially leading to a falsely negative study.

CONCLUSION

While highly accurate in identifying injuries necessitating intervention in hemodynamically unstable patients, the FAST examination underestimates intra-abdominal injuries in stable patients or traumatic injuries that do not result in hemoperitoneum.[28] The etiology, duration, or consequence of free fluid findings on US especially in hemodynamically stable patients, must all be considered before making treatment decisions based simply off an US finding. One must simply remember that the primary objective of the FAST examination in trauma is to detect life-threatening internal bleeding to facilitate timely surgical intervention, rather than to rule out abdominal injuries altogether.

CHEST ULTRASOUND IN TRAUMA

Background

The limitations in the sensitivity of physical examination and chest x-ray (CXR) to diagnose a pneumothorax (PTX) in trauma are well known.[29,30] CXR is reported to be "suboptimal" in 30% of patients[31] and can miss up to 55% of traumatic pneumothoraces as most patients are supine.[32,33] While chest CT is clearly the gold standard for evaluating for chest trauma, the cost, radiation, and risk associated with transporting

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a critically injured patient are all limitations to chest CT.[10] LUS, on the other hand, serves as an extension of the physical examination and can be performed easily during a trauma resuscitation.[34,35] While the use of LUS to diagnose a PTX was first described in 1986,[36] the field of LUS truly expanded through the work of Dr Lichtenstein in the 1990s.[30] He and his colleagues described most of the major artifacts seen in LUS and also developed the criteria necessary to diagnose a PTX using LUS.[37] Following the first reported the use of LUS in trauma in the United States in 1999,[38] multiple studies have consistently shown high sensitivity and specificity for PTX detection.[39–42] In addition, a Cochrane review performed in 2020 reported that LUS would have a 3% false negative and 1% false positive rate, while CXR would have a 16% false negative rate but have no false positives.[43]

Technique

Several indications for LUS exist and the technique or probe used should be tailored to the reason for the examination.[44] While pleural assessment is best performed with a high-frequency linear probe, using a curvilinear or phased area probe provides more versatility during the evaluation of a trauma patient and should preferentially be used in this setting.[44,45] The US probe is oriented with the marker toward the patient's head. When assessing for PTX, the probe is placed on the anterior chest on the abdomen or lung preset, with the orientation marker toward the patient's head.[46,47] This orientation creates an image whereby the intercostal space (ICS) is bounded by the superior and inferior ribs, the so called "bat sign" (**Fig. 4**).[48] Single or multiple ICSs can be assessed rapidly by moving the probe cranially or caudally along the chest.[49]

While the mid-clavicular line was the original chest landmark for this examination, placing the probe along the sternum (medial to the mid-clavicular line) has been identified by CT scans to be the optimal position to screen for a PTX.[50] In addition, scanning through the third to fifth ICS is more likely to identify a PTX as opposed to the first or second spaces, which is intuitive when one recognizes that the highest point in the chest of a supine patient is around the fourth or fifth rib.[50] Finally, visualizing all 3 of the interspaces (third to fifth) improves the overall sensitivity to 88% and may be better than simply using one interspace.[32] That said, Helland and colleagues showed that a single view obtained at the third ICS was equivalent to a 4-point US assessment.[51]

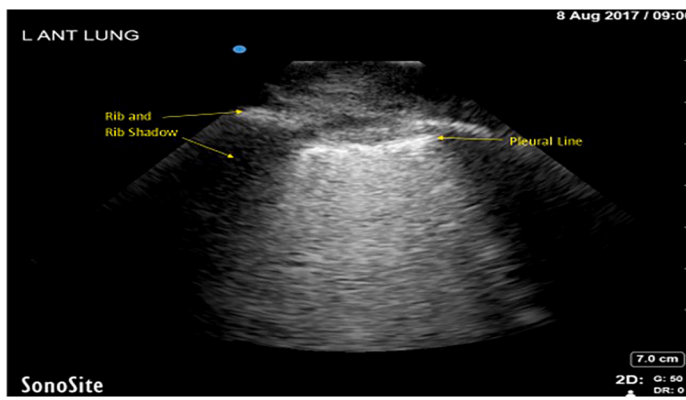

Fig. 4. Lung ultrasound demonstrating the "bat sign".

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Given the brief amount of time necessary to US several interspaces, there is little downside to visualizing several spaces in the parasternal position.

The pleura appears as a hyperechoic white line between the ribs (see **Fig. 4**), and lung movement creates a shimmering appearance, which Lichtenstein dubbed "lung sliding."[30] Decreasing the gain or adjusting the depth to a shallower view may facilitate visualization of the pleura when lung sliding is difficult to appreciate. Power and color Doppler modes can be used to enhance visualization of pleural motion.[52] Any pleural movement rules out pneumothorax at that location,[53] including the movement of the pleura as a result of the beating heart "lung pulse."[54] Other US findings that rule out the diagnosis of a PTX are the presence of "B-line" or "comet tails" (**Fig. 5**).[55] These hyperechoic, vertically oriented artifacts originate from the visceral pleura and move with the pleura. These artifacts are generated from the interlobular septa. If any air is between the chest wall and visceral pleura, the sound waves cannot reach the lung, and therefore, the presence of a B-line excludes a PTX.[55]

Lack of lung sliding does not definitively diagnose a PTX because several conditions can cause this finding (**Box 1**).[48,54,55] Confirming a PTX in a patient without lung sliding requires identification of a "lung point," which represents the lateral extent of the pneumothorax where pleural apposition returns (**Fig. 6**).[48] The lung point is the sudden appearance of lung sliding or B-lines with inspiration and their disappearance with exhalation. To identify a lung point, the ultrasonographer moves the probe within the interspace and toward the lateral wall of the chest until the lung slide reappears.[56] Loss of lung sliding coupled with the presence of a lung point has a 100% specificity for PTX, but unfortunately, identification of a lung point is not always possible.[48]

M-mode US, another method used to evaluate for PTX, creates an image that represents motion across time.[57] Normally, M-mode will generate a "seashore sign" where the lack of soft tissue movement creates a series of "waves" and the pleural movement results in a "sandy" appearance (**Fig. 7**).[54] In patients with a pneumothorax, the entire screen will appear as a series of waves, a finding sometimes known as the "stratosphere" or "barcode" sign (see **Fig. 7**).[57] Interestingly, the combination of both B-mode and M-mode images do appear to improve the accuracy of a novice to diagnose a PTX, but this effect does not persist once one has performed more than 250 scans.[58]

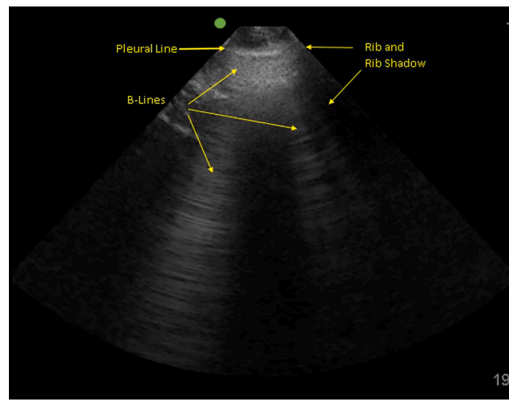

Fig. 5. Lung ultrasound demonstrating B-lines.

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Box 1
Nonpneumothorax causes for lack of lung sliding

Bullous emphysema

Chronic obstructive pulmonary disease

High levels of positive end-expiratory pressure

Massive atelectasis

Mainstem intubation

Pleural adhesions/pleurodesis

Presence of a chest tube

Pulmonary fibrosis

Adapted from Markota A, Golub J, Stožer A, et al. Absence of lung sliding is not a reliable sign of pneumothorax in patients with high positive end-expiratory pressure. Am J Emerg Med 2016;34(10):2034–6.

Evidence Supporting Lung Ultrasound for Diagnosing a Pneumothorax

Experimental models have demonstrated the ability of US to detect small amounts of air.[59] Using a pig model, Oveland and colleagues introduced increasing amounts of air into a chest while ultrasonographers with less than 1 year of LUS experience assessed for PTX. Using the presence of a lung point to diagnose a PTX, 65% detected a PTX after 10 cc of air was injected, 90% following 25 cc, and 100% detected a PTX once 50 cc of air had been injected.[59] By comparison, only 20% of pneumothoraces were noted on CXR after 50 cc had been injected. More concerning was the fact that one-third of CXRs failed to demonstrate a PTX even after 500 cc were instilled.[59] When comparing the performance of different probes, Oveland found that the high frequency probe detected a PTX at a smaller volume of air when compared with the microconvex probe, but the difference was only 8 cc.[59]

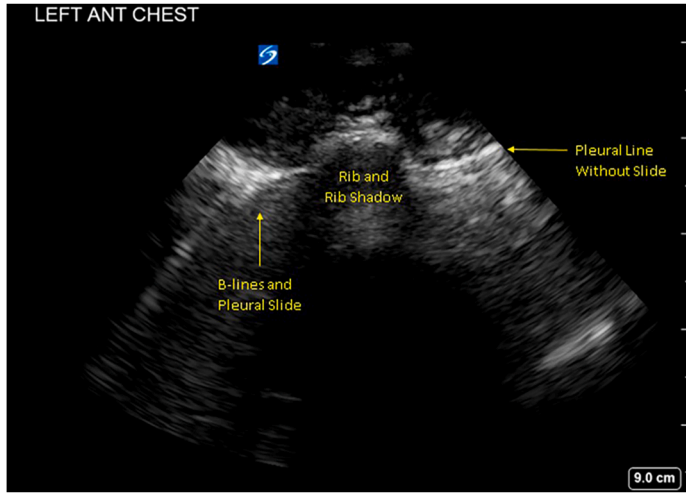

Fig. 6. Lung ultrasound demonstrating the "lung point".

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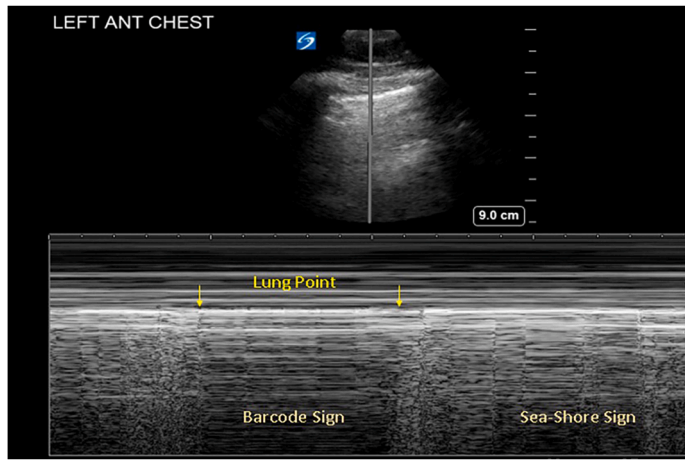

Fig. 7. M mode lung ultrasound image.

Lichtenstein's original article from 1995 noted a 98.1% success rate in being able to identify lung signs.[30] Multiple meta-analyses and systematic reviews have been performed to evaluate the utility of LUS in the detection of PTX.[39,60,61] Alrahjab and colleagues (13 studies) found a pooled sensitivity of 78.4%, specificity of 98.4% and area under receiver operator curve (AUC) of 0.98 compared with CXR of 39.8%, 99.3%, and 0.96, respectively.[39] Alrahjab also found that linear probes improved sensitivity (82%) but not specificity (76%) when compared with convex probes.[39] Staub and colleagues reviewed 17 studies specific to trauma patients, finding the prevalence of PTX to be 14%.[61] For this specific population, they calculated the sensitivity of LUS to be 81%, specificity to be 98%, with an AUC of 0.98.[61] Even with varying techniques and across different patient populations, LUS consistently outperforms CXR in the detection of PTX.

Pitfalls of Lung Ultrasound for Diagnosing a Pneumothorax

As with any imaging modality, one must be aware of the limitations and of the potential pitfalls associated with the study. POCUS examinations like LUS are particularly susceptible to errors because the provider both obtains and interprets the image. Additionally, some patient populations are expectantly difficult to US, for example, obese patients, those with chest dressings, patients with chronic obstructive pulmonary disease (COPD), or patients with subcutaneous emphysema.[52,62] Of the sonographic signs of PTX, lung sliding is the most susceptible to misinterpretation as a false positive (see **Box 1**).[30] While perhaps less important in the trauma bay where the likelihood of an alternate diagnosis is lower, one must still be aware that lack of lung sliding is not 100% sensitive for a PTX and that the presence of a lung point should be used to confirm the diagnosis.[45] Additionally, one must be aware of septate pneumothoraces. One must also be aware that LUS can identify very small pneumothoraces, some of which may not require treatment.[59] The extent of a PTX can be identified by locating the lung point as the location on the chest wall can be used to determine if the patient requires chest tube placement.[40] Soldati and colleagues observed patients with a PTX anterior to the mid-axillary line and found that only 10% of those patients required chest tube placement.[63]

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CONCLUSION

The evaluation of chest trauma has traditionally involved a physical examination and a CXR. Unfortunately, physical examination findings lack sensitivity or specificity to lead to a diagnosis. Similarly, CXR may be unhelpful and can only exclude a small number of life-threatening conditions. LUS as part of the FAST examination continues to gain acceptance as a valuable tool in the evaluation of patients as it overcomes many of the limitations described earlier.[64] While the sensitivity and specificity of LUS to detect a PTX makes this test particularly useful for the bedside provider, several recent publications have found that the presence of PTX on LUS does not always correlate with the need for chest tube placement.[65,66] As with most diagnostic imaging, the findings need to be taken in context with the clinical condition of the patient.

ROLE OF ULTRASOUND IN CARDIAC TRAUMA

Background

In the trauma setting, discovering an injury to the heart is predicated on maintaining an index of suspicion, which is in turn informed by the mechanism of injury (**Box 2**). Occult injuries to the heart can occur in both penetrating and blunt trauma. In blunt cardiac trauma, injury to the heart can occur both with and without direct injury to the heart. For the most part, the severity of injury to the heart is proportional to the amount of force sustained by the heart; however, the mechanism of injury and thus severity of injury is not always clearly identified. The acute trauma practitioner relies on history, physical examination, and extraneous clues to help guide index of suspicion—for example, presence of rib fractures, sternal fracture, pulmonary contusion, abdominal injury from compressive force, and extent of damage seen in the field (such as airbag deployment in a motor vehicle crash).[67,68] Furthermore, injuries to the heart can be delayed in presentation, emphasizing the need for observation and monitoring in trauma patients who present with a severe mechanism of injury. Serial bedside US of the heart is an important tool in the monitoring and assessment of symptomatic trauma patients or those who carry a high index of suspicion for cardiac injury. While outside the scope of this article, cardiac sequelae are frequently seen in severely

Box 2
Indications for use of cardiac ultrasound in trauma

- Penetrating chest trauma
- Elevated troponins
- Abnormal electrocardiogram (EKG)
- Neurogenic shock
- Deceleration injury
- Polytrauma
- Significant blunt chest trauma
- Persistent hypotension
- Chest pain or dyspnea
- Severe abdominal force
- Long bone fracture
- Significant comorbidities

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injured polytrauma patients, further underscoring the need for curiosity when approaching these patients.[69] Lastly, patients with preexisting comorbidities (congestive heart failure, liver disease, coronary artery disease) have increased mortality in the setting of cardiac trauma.[70] Keeping a patient's medical history in mind will help prompt additional screening and monitoring in these higher risk patients.

Technique

The phased-array (cardiac) probe (1–4 MHz frequency) is used for this examination. While originally described as a single subcostal view, the growing familiarity with cardiac US has demonstrated the benefit of obtaining additional views as the parasternal and apical views can add additional information.[69] When the decision is made to perform bedside cardiac US in trauma, the following questions help to guide evaluation of the heart (**Box 3**).

Multiple published protocols exist that combine various iterations of cardiac windows/views. Focus-assessed transthoracic echocardiography (FATE),[71] subcostal to apical, respiratory to parasternal (STARS),[72] and echocardiographic assessment using subxiphoid only (EASy)[73] are examples of these protocols (**Box 4**), but the most important step is following a consistent and methodical approach. Also, completing the entire protocol with its multiple windows and views is necessary as visualizing an abnormal finding in different views can help to further characterize it, and/or unveil unexpected pathology. Of note, the EASy protocol, a subcostal-only approach is a newly developed technique by which all major views of the heart (long axis, short axis, 4 chamber) are obtained from a single window in the subcostal position.[73] This may present advantages in patients with significant chest wall injury for whom traditional TTE windows may be unobtainable (ie, pneumothorax) and if TEE is not readily available.

Evaluation for Specific Cardiac Injuries

Pericardial effusion and tamponade

Evaluating for a pericardial effusion is a traditional part of the FAST examination in trauma. The fluid in the pericardium can lead to tamponade physiology, which depending on the severity of the clinical presentation, can necessitate surgical management ranging from pericardiocentesis to thoracotomy.[67] If an effusion is detected (particularly in a hemodynamically stable patient), it is helpful to pursue additional imaging to better characterize it as medical causes of pericardial effusions may be

Box 3
Questions to consider during cardiac ultrasound

- Is an effusion present? Is there evidence of tamponade physiology?
- Is the contractility normal, hyperdynamic, or depressed?
- Are wall motion abnormalities present?
- Are the valve structures normal? Is there regurgitation?
- Is there right ventricular (RV) enlargement? Greater than two-third the size of the left ventricle (LV) to suggest pulmonary embolism (PE)?
- Any echogenic debris in the inferior vena cava (IVC) or right heart to suggest PE or fat embolus?
- Where is the anterior leaflet of the mitral valve? Does it move toward the septum in systole?
- Is the IVC small/collapsable or is it dilated (which suggests other pathology)?

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Box 4
Examples of cardiac ultrasound protocols

Focus-assessed transthoracic echocardiography protocol
- Parasternal long
- Parasternal short
- Apical 4-chamber
- Apical 5-chamber
- Subcostal view

Subcostal to apical, respiratory to parasternal
- Subcostal view
- Apical 4-chamber
- Parasternal-respiratory

Echocardiographic assessment using subxiphoid only
- Long-axis plane
- Short-axis plane
- Inferior vena cava view

Adapted from Refs.[71–73]

identified.[74] Several criteria are helpful in determining tamponade physiology in the presence of a pericardial effusion (**Box 5**).[75] Keep in mind that tamponade physiology may be dynamic. An appropriately volume-resuscitated patient may have increased intracardiac filling pressures and thus classic signs of tamponade physiology such as right atrial collapse in systole or right ventricular collapse in diastole may be muted. Lastly, in the case of a delayed trauma presentation, the finding of echogenic debris in the pericardial fluid suggests chronicity of the effusion, which then in turn may affect management (**Fig. 8**A, B).

Blunt cardiac injury

Blunt cardiac injury (BCI) of the heart can range from the mildest of cardiac contusions causing tachycardia to rupture of the wall of a chamber (**Box 6**). In theory, contusion of the myocardial wall can be visualized as stiff and bright, signifying an edematous myocardial wall; however, in practice this is not always apparent.[76] The best published screening for myocardial contusion remains cardiac monitoring for tachycardia, EKG assessing for arrhythmia or conduction delay, and the troponin assay.[68] Bedside cardiac US should follow any positive results from screening, with serial examinations as part of ongoing monitoring.

BCI may also result in valve damage, particularly if the heart receives a blow during either diastole when the aortic valve is closed, or systole when atrioventricular valves

Box 5
Echocardiographic signs of cardiac tamponade

Right atrial collapse in systole (first one-third of systole)

Right ventricular collapse in diastole (a more sensitive sign)

An underfilled left ventricle and right ventricle

An enlarged or plethoric IVC without respirophasic variation

Adapted from Alerhand S, Carter JM. What echocardiographic findings suggest a pericardial effusion is causing tamponade? Am J Emerg Med 2019;37(2):321–6.

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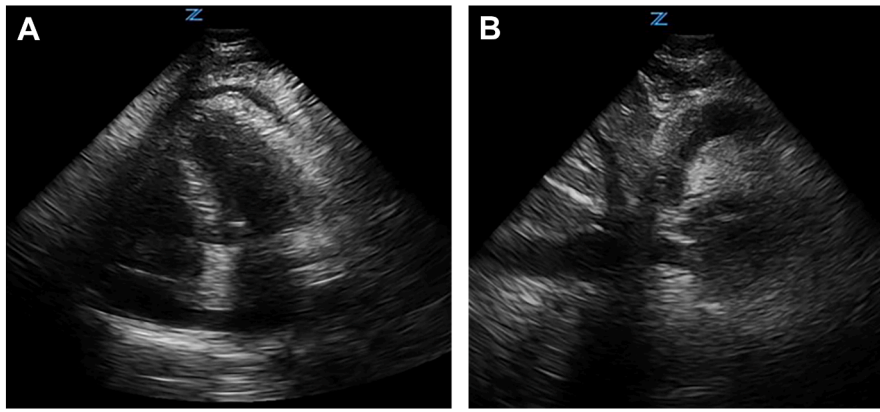

Fig. 8. (*A, B*) Cardiac images with echogenic debris within the paricardium.

may be closed.[69,76] Structural damage to the valve can be seen on echo but color Doppler is necessary to assess for and identify valvular regurgitation.[77] As the population ages, the challenge will be determining whether the presence of valvular regurgitation is acute or chronic, and if the valvular dysfunction is contributing to hemodynamic instability. The patient's medical history, mechanism of injury, and finding damaged valvular structures such as a flail leaflet or flail chordae, can all be clues to the chronicity of the valvular disease. Generally, hypotension in the acute trauma setting should be attributed to hemorrhage but collapse from an acutely regurgitant valve does occur. If there is any concern or positive findings on bedside cardiac US in a patient with a blunt cardiac trauma obtaining a formal echocardiogram is necessary.

Pericardial damage may also occur, causing displacement of the heart and/or bleeding into the pleural space. Most patients with severe abrupt chamber rupture die in the field. However, for those that do survive to reach the hospital, prompt recognition and appropriate surgical intervention are needed. There is debate in the literature as to which chamber is most commonly injured, and whether a sternal fracture or rib fractures are correlated with severity of BCI.[68,78,79] Typically, the right-sided chambers are most at risk for injury with a direct blow to the chest; however, injury to the apex of the LV can occur if the left lateral chest wall is struck.[80] Blunt injury may also damage epicardial coronary arteries, causing ischemia to a corresponding myocardial vascular distribution. This may show up on bedside cardiac US as discrete

Box 6
Complications of blunt cardiac injury

- Myocardial contusion
- Myocardial rupture
- Pericardial rupture
- Septal injury
- Valvular injury
- Commotio cordis

Adapted from Huis In't Veld MA, Craft CA, Hood RE. Blunt cardiac trauma review. Cardiol Clin 2018;36(1):183–91.

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wall motion abnormality along the territory of the injured coronary artery. However, wall motion abnormality can be subtle and difficult to detect, and it may require a formal echocardiogram to best characterize the degree of myocardial dysfunction.

Indirect cardiac injury

Cardiac injuries occurring without direct trauma to the heart can be easily missed, because the mechanism of injury is not always obvious (**Box 7**). One entity that deserves special mention is systolic anterior motion of the mitral valve (SAM). This may be seen in hypotensive patients with a hyperdynamic heart as the hypertrophic left ventricle can pull the anterior mitral leaflet into the LV outflow.[81] Of note, the presence of SAM is a diagnosis that can only be made with US. In rapid tachycardia, finding SAM may require saving a clip of the LV outflow tract, then replaying the clip slowly to see where the anterior leaflet of the mitral valve travels during systole.

Limitations of Cardiac Ultrasound in Trauma

The limitations of cardiac US in trauma are similar to those in any patient. In a normotensive trauma patient, an abnormal finding on cardiac US does not necessarily identify a potential life threat. In these settings, serial monitoring, observation, and serial bedside cardiac USs are necessary to better characterize a patient's clinical situation and trajectory. Furthermore, there are mimickers of pericardial effusions such as pericardial fat pads and pleural effusions that can be challenging to differentiate.[82] Lastly, false negative cardiac US studies have been documented in trauma patients, particularly in detecting pericardial effusion in penetrating injury to the mediastinum.[83] The overarching limitation for detecting traumatic cardiac injuries using US is not so much not finding them but rather not looking for them.

CONCLUSION

The evolution of point-of-care ultrassound (POCUS) has expanded the role of cardiac US in trauma beyond the simple evaluation of pericardial effusion. Cardiac US can be performed rapidly, with a brief and methodical approach while resuscitation is ongoing, and has been shown to alter the treatment plan in a significant number of patients.[84] Any concerning findings should be followed up with repeated cardiac assessment, close monitoring, and usually a formal echocardiogram.

ROLE OF ULTRASOUND IN TRIAGE AND PREHOSPITAL SETTINGS

POCUS conducted during prehospital and mass casualty incidents (MCIs) can significantly influence clinical decisions, notifications, choice of transport, and hospital

Box 7
Causes of indirect cardiac injury

- Wall or valve injuries due to abdominal compression
- Myocardial depression due to sympathetic nervous system dysfunction
- Fat emboli from long bone fracture
- Acute pulmonary embolus resulting in right ventricular failure
- Functional outflow obstruction in hyperdynamic heart

Adapted from Saranteas T, Mavrogenis AF, Mandila C, et al. Ultrasound in cardiac trauma. J Crit Care 2017;38:144–51; and Biffl WL, Fawley JA, Mohan RC. Diagnosis and management of blunt cardiac injury: what you need to know. J Trauma Acute Care Surg 2024;96(5):685–93.

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selection; however, very few studies demonstrate improved patient-centered outcomes.[85,86] A positive finding on POCUS strongly indicates the need for intervention and may be a useful tool in prehospital triage.[87] Unfortunately, the negative predictive values are not sufficiently robust to advocate for using POCUS alone to rule out serious injuries.[88]

The use of POCUS in MCIs continues to develop. POCUS may be useful for initial triage, but particularly for retriage to help determine extended prehospital treatment and evacuation prioritization. It generally has higher sensitivity than physical examination and vital signs alone. Occasionally, hospitals can be incapacitated by disasters, leading to a surge in trauma patients. Multiple injured patients may need help in austere geographic locations where radiological investigations are not available. Protocols like chest, abdomen, vena cava, and extremities for acute triage (CAVEAT)[89] and classical focused assessment sonography for trauma and extremity and respiratory evaluation (FASTER)[90] for MCIs include US examination of extremities and have remote transmission capabilities if available.[91,92] Literature supports POCUS efficacy in diagnosing extremity fractures both in hospital settings and during MCIs including systemic review with pooled US sensitivity and specificity of 97% and 95%, respectively, for detecting distal forearm fractures.[93,94] In mass casualty situation, POCUS has been studied in limited applications of triage and treatment for resuscitation and in musculoskeletal injury (fractures and acute compartment syndrome).[95,96]

The practice of prehospital POCUS was implemented 2 decades ago across several emergency medical services (EMSs) in Europe, Australia, and North America with acceptable results.[97–100] Since that time, several studies have discussed the potential of POCUS in assessment, triage, and resource allocation.[14,101,102] Moreover, FAST can be repeated during transportation and images securely routed to surgical teams.[103,104] Testing of handheld units has explored satellite and mobile wireless transmission of FAST, achieving over 90% correct interpretation of images in studies.[88,97] These technological advancements hold immense potential in disaster scenarios, enabling precise field triage and patient care direction, even in challenging environments. That said, optimal utilization of prehospital US requires adequate training, experience, and awareness of its technical constraints.[105]

SUMMARY

The ongoing advancements in POCUS and the wide availability of US have revolutionized trauma care. In only a few decades, the FAST examination has evolved beyond a simple assessment for free abdominal fluid to the point that whole body US is routinely employed in the evaluation of a trauma patient. Ultimately, POCUS is simply a tool that can be used in conjunction with all of the other available resources to make a clinical decision. The advantages and disadvantages of this modality are well-described but POCUS in trauma will continue to move beyond its traditional role.

CLINICS CARE POINTS

- Focused assessment with sonography in trauma (FAST).
  - Pearl: FAST examination is effective in detecting free intraperitoneal fluid in blunt trauma.
  - Pearl: FAST examination is versatile and can be used across various patient conditions.
  - Pitfall: Limited sensitivity for detecting solid organ injuries and retroperitoneal structures.
  - Pitfall: False positives can occur in the presence of resuscitative fluids.
  - Pitfall: Obesity and patient anatomy can hinder obtaining optimal views.
- Chest ultrasound (US) in trauma

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- Pearl: LUS outperforms CXR in detecting small and occult pneumothoraces.
- Pearl: LUS can be performed rapidly at the bedside during trauma resuscitation.
- Pitfall: Difficulty in obtaining clear views in obese patients or those with chest dressings.
- Pitfall: Lack of lung sliding does not definitively diagnose pneumothorax; a lung point is necessary for confirmation.

- Cardiac US in trauma
  - Pearl: Bedside cardiac US is crucial for evaluating cardiac trauma and assessing for pericardial effusion or tamponade.
  - Pearl: Cardiac US protocols provide a framework to perform more comprehensive examinations.
  - Pitfall: Dependency on operator skill and experience in interpreting US findings.
  - Pitfall: Not all cardiac injuries may be immediately apparent and ongoing monitoring may be necessary.
  - Pitfall: Limited ability to detect subtle myocardial injuries or valvular abnormalities.

DISCLOSURE

The authors have nothing to disclose.

REFERENCES

1. Miller MT, Pasquale MD, Bromberg WJ, et al. Not so FAST. J Trauma 2003;54(1):52–9 [discussion: 9–60].
2. Nishijima DK, Simel DL, Wisner DH, et al. Does this adult patient have a blunt intra-abdominal injury? JAMA 2012;307(14):1517–27.
3. Neeki MM, Hendy D, Dong F, et al. Correlating abdominal pain and intra-abdominal injury in patients with blunt abdominal trauma. Trauma Surg Acute Care Open 2017;2(1):e000109.
4. Benjamin ER, Jakob DA, Myers L, et al. The trauma pelvic X-ray: not all pelvic fractures are created equally. Am J Surg 2022;224(1 Pt B):489–93.
5. Dillon DG, Rodriguez RM. Screening performance of the chest X-ray in adult blunt trauma evaluation: is it effective and what does it miss? Am J Emerg Med 2021;49:310–4.
6. Williams SR, Perera P, Gharahbaghian L. The FAST and E-FAST in 2013: trauma ultrasonography: overview, practical techniques, controversies, and new frontiers. Crit Care Clin 2014;30(1):119–50, vi.
7. Matsushima K, Frankel HL. Beyond focused assessment with sonography for trauma: ultrasound creep in the trauma resuscitation area and beyond. Curr Opin Crit Care 2011;17(6):606–12.
8. Hoffmann R, Nerlich M, Muggia-Sullam M, et al. Blunt abdominal trauma in cases of multiple trauma evaluated by ultrasonography: a prospective analysis of 291 patients. J Trauma 1992;32(4):452–8.
9. Röthlin MA, Näf R, Amgwerd M, et al. Ultrasound in blunt abdominal and thoracic trauma. J Trauma Acute Care Surg 1993;34(4):488–95.
10. Tso P, Rodriguez A, Cooper C, et al. Sonography in blunt abdominal trauma: a preliminary progress report. J Trauma Acute Care Surg 1992;33(1):39–44.
11. Mateer JR, Ogata M, Kefer MP, et al. Prospective analysis of a rapid trauma ultrasound examination performed by emergency physicians. J Trauma Acute Care Surg 1995;38(6):879–85.
12. Rozycki GS, Ochsner MG, Schmidt JA, et al. A prospective study of surgeon-performed ultrasound as the primary adjuvant modality for injured patient assessment. J Trauma Acute Care Surg 1995;39(3):492–500.

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13. Montoya J, Stawicki SP, Evans DC, et al. From FAST to E-FAST: an overview of the evolution of ultrasound-based traumatic injury assessment. Eur J Trauma Emerg Surg 2016;42(2):119–26.
14. El ZT, El Sayed MJ. Prehospital ultrasound in trauma: a review of current and potential future clinical applications. J Emerg Trauma Shock 2018;11(1):4–9.
15. Lobo V, Hunter-Behrend M, Cullnan E, et al. Caudal edge of the liver in the right upper quadrant (RUQ) view is the most sensitive area for free fluid on the FAST exam. West J Emerg Med 2017;18(2):270–80.
16. Ormsby EL, Geng J, McGahan JP, et al. Pelvic free fluid: clinical importance for reproductive age women with blunt abdominal trauma. Ultrasound Obstet Gynecol 2005;26(3):271–8.
17. Richards JR, McGahan JP, Simpson JL, et al. Bowel and mesenteric injury: evaluation with emergency abdominal US. Radiology 1999;211(2):399–403.
18. Chiu WC, Cushing BM, Rodriguez A, et al. Abdominal injuries without hemoperitoneum: a potential limitation of focused abdominal sonography for trauma [FAST]. J Trauma Inj Infect Crit Care 1997;42(4):617–25.
19. Glaser K, Tschmelitsch J, Klingler P, et al. Ultrasonography in the management of blunt abdominal and thoracic trauma. Arch Surg 1994;129(7):743–7.
20. Desai N, Harris T. Extended focused assessment with sonography in trauma. BJA Educ 2018;18(2):57–62.
21. Chiu WC, Cushing BM, Rodriguez A, et al. Abdominal injuries without hemoperitoneum: a potential limitation of focused abdominal sonography for trauma (FAST). J Trauma Acute Care Surg 1997;42(4):617–25.
22. Carter JW, Falco MH, Chopko MS, et al. Do we really rely on fast for decision-making in the management of blunt abdominal trauma? Injury 2015;46(5):817–21.
23. Meisinger QC, Brown MA, Dehqanzada ZA, et al. A 10-year retrospective evaluation of ultrasound in pregnant abdominal trauma patients. Emerg Radiol 2016;23(2):105–9.
24. Richards JR, McGahan JP. Focused assessment with sonography in trauma (FAST) in 2017: what radiologists can learn. Radiology 2017;283(1):30–48.
25. Slutzman JE, Arvold LA, Rempell JS, et al. Positive FAST without hemoperitoneum due to fluid resuscitation in blunt trauma. J Emerg Med 2014;47(4):427–9.
26. Sierzenski PR, Schofer JM, Bauman MJ, et al. The double-line sign: a false positive finding on the Focused Assessment with Sonography for Trauma (FAST) examination. J Emerg Med 2011;40(2):188–9.
27. Yıldız MK, Ozkan E, Odabaşı HM, et al. Analysis of 120 patients with abdominal stab wound focusing on diagnostic role of fast. Int J Clin Exp Med 2014;7(5):1386.
28. Dammers D, El Moumni M, Hoogland II, et al. Should we perform a FAST exam in haemodynamically stable patients presenting after blunt abdominal injury: a retrospective cohort study. Scand J Trauma Resusc Emerg Med 2017;25(1):1.
29. Inocencio M, Childs J, Chilstrom ML, et al. Ultrasound findings in tension pneumothorax: a case report. J Emerg Med 2017;52(6):e217–20.
30. Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically III. Chest 1995;108(5):1345–8.
31. Xirouchaki N, Magkanas E, Vaporidi K, et al. Lung ultrasound in critically ill patients: comparison with bedside chest radiography. Intensive Care Med 2011;37(9):1488–93.
32. Kiley S, Cassara C, Fahy BG. Lung ultrasound in the intensive care unit. J Cardiothorac Vasc Anesth 2015;29(1):196–203.

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33. Schellenberg M, Inaba K, Bardes JM, et al. The combined utility of extended focused assessment with sonography for trauma and chest x-ray in blunt thoracic trauma. J Trauma Acute Care Surg 2018;85(1):113–7.
34. Williamson JP, Grainge C, Parameswaran A, et al. Thoracic ultrasound: what non-radiologists need to know. Curr Pulmonol Rep 2017;6(1):39–47.
35. Ianniello S, Di Giacomo V, Sessa B, et al. First-line sonographic diagnosis of pneumothorax in major trauma: accuracy of e-FAST and comparison with multidetector computed tomography. Radiol Med 2014;119(9):674–80.
36. Kirkpatrick AW, Sirois M, Laupland KB, et al. Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the extended focused assessment with sonography for trauma (EFAST). J Trauma Inj Infect Crit Care 2004;57(2):288–95.
37. Lichtenstein D, van Hooland S, Elbers P, et al. Ten good reasons to practice ultrasound in critical care. Anaesthesiol Intensive Ther 2014;46(5):323–35.
38. Dulchavsky SA, Schwarz KL, Kirkpatrick AW, et al. Prospective evaluation of thoracic ultrasound in the detection of pneumothorax. J Trauma 2001;50(2):201–5.
39. Alrajab S, Youssef AM, Akkus NI, et al. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. Crit Care 2013;17(5):R208.
40. Soldati G, Testa A, Sher S, et al. Occult traumatic pneumothorax: diagnostic accuracy of lung ultrasonography in the emergency department. Chest 2008;133(1):204–11.
41. Hyacinthe AC, Broux C, Francony G, et al. Diagnostic accuracy of ultrasonography in the acute assessment of common thoracic lesions after trauma. Chest 2012;141(5):1177–83.
42. Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. Acad Emerg Med 2005;12(9):844–9.
43. Chan KK, Joo DA, McRae AD, et al. Chest ultrasonography versus supine chest radiography for diagnosis of pneumothorax in trauma patients in the emergency department. Cochrane Database Syst Rev 2020;7(7):CD013031.
44. Beckh S, Bölcskei PL, Lessnau K-D. Real-time chest ultrasonography. Chest 2002;122(5):1759–73.
45. Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. Chest 2008;134(1):117–25.
46. Volpicelli G, Mussa A, Garofalo G, et al. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. Am J Emerg Med 2006;24(6):689–96.
47. Mayo PH, Doelken P. Pleural ultrasonography. Clin Chest Med 2006;27(2):215–27.
48. Lichtenstein D, Meziere G, Biderman P, et al. The "lung point": an ultrasound sign specific to pneumothorax. Intensive Care Med 2000;26(10):1434–40.
49. Koenig SJ, Narasimhan M, Mayo PH. Thoracic ultrasonography for the pulmonary specialist. Chest 2011;140(5):1332–41.
50. Kiley S, Tighe P, Hajibrahim O, et al. Retrospective computed tomography mapping of intrapleural air may demonstrate optimal window for ultrasound diagnosis of pneumothorax. J Intensive Care Med 2014;29(6):342–7.
51. Helland G, Gaspari R, Licciardo S, et al. Comparison of four views to single-view ultrasound protocols to identify clinically significant pneumothorax. Acad Emerg Med 2016;23(10):1170–5.

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52. Rose G, Siadecki S, Tansek R, et al. A novel method of assessing for lung sliding using Doppler imaging. Am J Emerg Med 2017;35(11):1738–42.
53. Lichtenstein DA, Mezière G, Lascols N, et al. Ultrasound diagnosis of occult pneumothorax. Crit Care Med 2005;33(6):1231–8.
54. Shrestha GS, Weeratunga D, Baker K. Point-of-Care lung ultrasound in critically ill patients. Rev Recent Clin Trials 2018;13(1):15–26.
55. Lichtenstein D, Meziere G, Biderman P, et al. The comet-tail artifact: an ultrasound sign ruling out pneumothorax. Intensive Care Med 1999;25(4):383–8.
56. Lichtenstein D. Novel approaches to ultrasonography of the lung and pleural space: where are we now? Breathe (Sheff) 2017;13(2):100–11.
57. Ouellet J-F, Ball C, Panebianco N, et al. The sonographic diagnosis of pneumothorax. J Emergencies, Trauma, Shock 2011;4(4):504–7.
58. Avila J, Smith B, Mead T, et al. Does the addition of M-mode to B-mode ultrasound increase the accuracy of identification of lung sliding in traumatic pneumothoraces? J Ultrasound Med 2018;37(11):2681–7.
59. Oveland NP, Soreide E, Lossius HM, et al. The intrapleural volume threshold for ultrasound detection of pneumothoraces: an experimental study on porcine models. Scand J Trauma Resuscitation Emerg Med 2013;21:11.
60. Alrajhi K, Woo MY, Vaillancourt C. Test characteristics of ultrasonography for the detection of pneumothorax: a systematic review and meta-analysis. Chest 2012;141(3):703–8.
61. Staub LJ, Biscaro RRM, Kaszubowski E, et al. Chest ultrasonography for the emergency diagnosis of traumatic pneumothorax and haemothorax: a systematic review and meta-analysis. Injury 2018;49(3):457–66.
62. Liccardo B, Martone F, Trambaiolo P, et al. Incremental value of thoracic ultrasound in intensive care units: indications, uses, and applications. World J Radiol 2016;8(5):460–71.
63. Soldati G, Testa A, Silva FR, et al. Chest ultrasonography in lung contusion. Chest 2006;130(2):533–8.
64. Schmidt GA, Koenig S, Mayo PH. Shock: ultrasound to guide diagnosis and therapy. Chest 2012;142(4):1042–8.
65. Butts CC, Cline D, Pariyadath M, et al. Diagnostic inaccuracies using extended focused assessment with sonography in trauma for traumatic pneumothorax. Am Surg 2023;89(6):2272–5.
66. DeLoach JP, Reif RJ, Smedley WA, et al. Are chest radiographs or ultrasound more accurate in predicting a pneumothorax or need for a thoracostomy tube in trauma patients? Am Surg 2023;89(9):3751–6.
67. Offenbacher J, Liu R, Venitelli Z, et al. Hemopericardium and cardiac tamponade after blunt thoracic trauma: a case series and the essential role of cardiac ultrasound. J Emerg Med 2021;61(3):e40–5.
68. Clancy K, Velopulos C, Bilaniuk JW, et al. Screening for blunt cardiac injury: an Eastern Association for the Surgery of Trauma practice management guideline. J Trauma Acute Care Surg 2012;73(5 Suppl 4):S301–6.
69. Saranteas T, Mavrogenis AF, Mandila C, et al. Ultrasound in cardiac trauma. J Crit Care 2017;38:144–51.
70. El-Qawaqzeh K, Anand T, Richards J, et al. Predictors of mortality in blunt cardiac injury: a nationwide analysis. J Surg Res 2023;281:22–32.
71. Nagre AS. Focus-assessed transthoracic echocardiography: implications in perioperative and intensive care. Ann Card Anaesth 2019;22(3):302–8.
72. Nikravan S, Bughrara N, Klick J, et al. An echocardiographic approach for the management of shock: the subcostal to apical, respiratory to parasternal-

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cardiac to respiratory, aortic to stomach protocol. Semin Ultrasound CT MR 2024;45(1):74–83.
73. Bughrara N, Renew JR, Alabre K, et al. Comparison of qualitative information obtained with the echocardiographic assessment using subcostal-only view and focused transthoracic echocardiography examinations: a prospective observational study. Can J Anaesth 2022;69(2):196–204.
74. Press GM, Miller S. Utility of the cardiac component of FAST in blunt trauma. J Emerg Med 2013;44(1):9–16.
75. Alerhand S, Carter JM. What echocardiographic findings suggest a pericardial effusion is causing tamponade? Am J Emerg Med 2019;37(2):321–6.
76. Weber B, Lackner I, Baur M, et al. Early myocardial damage (EMD) and valvular insufficiency result in impaired cardiac function after multiple trauma in pigs. Sci Rep 2021;11(1):1151.
77. Huis In 't Veld MA, Craft CA, Hood RE. Blunt cardiac trauma review. Cardiol Clin 2018;36(1):183–91.
78. Marcolini EG, Keegan J. Blunt cardiac injury. Emerg Med Clin North Am 2015; 33(3):519–27.
79. Offenbacher J, Kim PK, Nguyen V, et al. Association of thoracic cage fractures and pericardial effusion in blunt trauma. Am J Emerg Med 2021;50:729–32.
80. Biffl WL, Fawley JA, Mohan RC. Diagnosis and management of blunt cardiac injury: what you need to know. J Trauma Acute Care Surg 2024;96(5):685–93.
81. Sobczyk D. Dynamic left ventricular outflow tract obstruction: underestimated cause of hypotension and hemodynamic instability. J Ultrason 2014;14(59): 421–7.
82. Bronshteyn YS, Hashmi N, Privratsky JR, et al. Blood or fat? Differentiating hemopericardium versus epicardial fat using focused cardiac ultrasound. Diagnostics (Basel) 2024;14(8):818.
83. Governatori NJ, Saul T, Siadecki SD, et al. Ultrasound in the evaluation of penetrating thoraco-abdominal trauma: a review of the literature. Med Ultrason 2015; 17(4):528–34.
84. Ferrada P, Evans D, Wolfe L, et al. Findings of a randomized controlled trial using limited transthoracic echocardiogram (LTTE) as a hemodynamic monitoring tool in the trauma bay. J Trauma Acute Care Surg 2014;76(1):31–7 [discussion: 7–8].
85. Bøtker MT, Jacobsen L, Rudolph SS, et al. The role of point of care ultrasound in prehospital critical care: a systematic review. Scand J Trauma Resuscitation Emerg Med 2018;26:1–14.
86. Mercer CB, Ball M, Cash RE, et al. Ultrasound use in the prehospital setting for trauma: a systematic review. Prehosp Emerg Care 2021;25(4):566–82.
87. Walcher F, Weinlich M, Conrad G, et al. Prehospital ultrasound imaging improves management of abdominal trauma. Br J Surg 2006;93(2):238–42.
88. Press GM, Miller SK, Hassan IA, et al. Prospective evaluation of prehospital trauma ultrasound during aeromedical transport. J Emerg Med 2014;47(6): 638–45.
89. Wydo S, Seamon M, Melanson S, et al. Portable ultrasound in disaster triage: a focused review. Eur J Trauma Emerg Surg 2016;42:151–9.
90. Dulchavsky SA, Henry SE, Moed BR, et al. Advanced ultrasonic diagnosis of extremity trauma: the FASTER examination. J Trauma Acute Care Surg 2002;53(1): 28–32.

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91. Sargsyan AE, Hamilton DR, Jones JA, et al. FAST at MACH 20: clinical ultrasound aboard the International Space Station. J Trauma Acute Care Surg 2005;58(1):35–9.
92. Crawford I, McBeth PB, Mitchelson M, et al. Telementorable "just-in-time" lung ultrasound on an iPhone. J Emergencies, Trauma, Shock 2011;4(4):526–7.
93. Hamer DD-D, Blanker MH, Edens MA, et al. Ultrasound for distal forearm fracture: a systematic review and diagnostic meta-analysis. PLoS One 2016; 11(5):1–16.
94. Abu-Zidan FM. Ultrasound diagnosis of fractures in mass casualty incidents. World J Orthoped 2017;8(8):606.
95. Puebla DL, Apicella M, Mechanic OJ, et al. Point of care ultrasound needle guidance to assist diagnosis of acute gluteal compartment syndrome. Am J Emerg Med 2022;62:147.e5–7.
96. Abu-Zidan FM, Jawas A, Idris K, et al. Surgical and critical care management of earthquake musculoskeletal injuries and crush syndrome: a collective review. Turk J Emerg Med 2024;24(2):67–79.
97. Dittrich K, ABU-ZIDAN FM. Role of ultrasound in mass-casualty situations. Int J Disaster Med 2004;2(1–2):18–23.
98. O'Dochartaigh D, Douma M. Prehospital ultrasound of the abdomen and thorax changes trauma patient management: a systematic review. Injury 2015;46(11): 2093–102.
99. Sippel S, Muruganandan K, Levine A, et al. Use of ultrasound in the developing world. Int J Emerg Med 2011;4:1–11.
100. Becker DM, Tafoya CA, Becker SL, et al. The use of portable ultrasound devices in low-and middle-income countries: a systematic review of the literature. Trop Med Int Health 2016;21(3):294–311.
101. van der Weide L, Popal Z, Terra M, et al. Prehospital ultrasound in the management of trauma patients: systematic review of the literature. Injury 2019;50(12): 2167–75.
102. Lucas B, Hempel D, Otto R, et al. Prehospital FAST reduces time to admission and operative treatment: a prospective, randomized, multicenter trial. Eur J Trauma Emerg Surg 2022;48(4):2701–8.
103. Ma OJ, Norvell JG, Subramanian S. Ultrasound applications in mass casualties and extreme environments. Crit Care Med 2007;35(5 Suppl):S275–9.
104. Training in diagnostic ultrasound: essentials, principles and standards. Report of a WHO Study Group. World Health Organ Tech Rep Ser 1998;875. i–46.
105. Baloescu C, Parhar A, Liu R, et al. Effect of point-of-care ultrasound on clinical outcomes in low-resource settings: a systematic review. Ultrasound Med Biol 2022;48(9):1711–9.

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